Robert Manning
(A Historical Perspective)

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OVERVIEW

Robert Manning (1816-1897) wrote his first paper on hydraulics in 1851 and his last in 1895. During this period, Manning devoted considerable effort to the development of a simple, dimensionally homogeneous formula for open-channel flow.

In the end, his paper "On the Flow of Water in Open Channels and Pipes," published in *Transactions of the Institution of Civil Engineers of Ireland* (Manning 1891), became the primary reference for his work and the source of Manning's monomial equation:

$$V = \frac{k_n}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad (1)$$

where V is the cross-sectional average velocity, R is the hydraulic radius, S is the energy slope, k_n=1.486 for English units and k_n=1 for SI units, and n is the Manning resistance coefficient. (The original equation was presented with k_n/n represented as C, rather than the current convention presented here).

Understanding the applicability and limitations of any analytical tool requires an understanding of the context in which it was developed and the use for which it was intended. This is the story of the Manning equation.

EARLY YEARS

Born in Normandy, Manning and his mother moved to Waterford, Ireland, in 1826 after the death of his father. He worked as an accountant for his uncle, John Stephans, from 1834 through 1845, and was drafted into the Arterial Drainage Division of the Irish Office of Public Works in 1846 due to an expansion of this office during the Irish famine years. He served as a clerk, accountant, and draftsman until he was appointed assistant engineer to Samuel Roberts later that year. Upon Roberts' transfer in 1848, Manning was appointed as District Engineer, a position he held until 1855.

From 1855 to 1869, Manning was engaged by the Marquis of Downshire, during which time he conducted surveys of estates in Ireland, oversaw construction of the Dundrum Bay Harbor, and designed a water supply system for the city of Belfast. Manning was not reappointed to the position after the Marquis' death, so he returned to the Office of Public Works in 1869 as Assistant to the Chief Engineer. He was appointed Chief Engineer in 1874, and held this post until his retirement in 1891. As Chief Engineer, he was responsible for numerous harbor, navigation, arterial drainage, and sewerage projects.

It is interesting to note that Manning received no formal training in fluid mechanics or engineering and would have likely remained an accountant/clerk had it not been for the Irish famine. In an 1895 paper, Manning describes how he "devoured" the *Traite d'Hydraulique of d'Aubisson des Voisons* as a newly appointed District Engineer in 1848 in order to teach himself hydraulics. In his writings he continually refers to the great pioneers of hydraulic engineering and theory: Chezy, Du Buat, and Eytelwein, as

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well as to his contemporaries: Darcy, Bazin and Kutter. It is obvious that his accounting background and pragmatism influenced his work. He had a strong drive to reduce problems to their simplest form, and he expressed disdain for mathematical formulations.

THE EQUATION

Dooge (1992) quotes Robert Manning in his Presidential Address to the Institution of Civil Engineers of Ireland:

> *And now a few words, again addressed to the younger members, with regard to the use of formulae. I very much fear that if I were to illustrate any observations I have to make with chalk on the black-board, a dozen note-books would be taken out, the formula copied without investigation, probably to my discredit, and eventually worked to death. It should be remembered that a formula is only a short memorandum (put in a shape fit for ready use) of the result arrived at after a patient consideration of the facts and principles upon which it is founded, and to use it without investigation is the merest empiricism.*

Manning began his diligent search for a useful formula by evaluating and comparing the seven best known open-channel flow formulae of the time with the idea that "by taking the mean results of all of them an approximation to the truth might be arrived at." The seven formulae chosen by Manning were those of Du Buat (1786), Eytelwein (1814), Weisbach (1845), St. Venant (1851), Neville (1860), Darcy and Bazin (1865), and Ganguillet and Kutter (1869). Manning calculated the velocity obtained from each formula for a given slope and for R values from 0.25 to 30 m. The mean of the seven velocities for each condition was taken as the best approximation and a best-fit line of the following expression applied:

$$V = 32\sqrt{RS(1+R^{1/3})} \qquad (2)$$

Manning described this equation as "entirely empirical" and suggested that a better approach would be to use an equation of the form:

$$V = CS^{1/2}R^{x} \qquad (3)$$

Manning accepted the basic form of Equation 3 and turned to a more detailed analysis of existing data. After dismissing the Mississippi River observations by Humphreys and Abbot and giving greatest weight to the observations of Bazin, Manning determined the value of the exponent to be x = 0.666. In 1885, Manning arrived at the equation:

$$V = CR^{2/3}S^{1/2} \qquad (4)$$

Manning later rejected this formula on the basis that (a) it required the extraction of a cube root (not a trivial concern at that time), and (b) the equation lacked dimensional homogeneity. So concerned was Manning with the issue of dimensional homogeneity that in his 1889 paper, he proposed the following equation:

$$V = C\sqrt{gS}\,[\sqrt{R} + \frac{0.22}{\sqrt{m}}(R - 0.15m)] \qquad (5)$$

in which m is the barometric pressure in meters mercury.

Despite doubts about the mathematical form used for Equation 5, Manning submitted it as being preferential to Equation 4, which was also presented in the paper. In his 1895 paper, Manning did not mention Equation 4, but rather suggested Equation 5 as the appropriate formula and named it after himself.

Others, however, preferred Equation 4 and in subsequent correspondence, in particular with Flamant, Manning noted that "the reciprocal of C corresponds closely with that of n, as determined by Ganguillet and Kutter; both C and n being constant for the same channel." In his French text, Flamant (1891) noted that, with C

proportional to $R^{1/6}$, in metric units, $V = C R^{2/3} S^{1/2}$ (in which C is supposedly the same as the reciprocal of Kutter's n) and called this Manning's formula apparently unaware of the earlier conclusions by Gauckler and Hagen that were similar.

In addition to Flamant, a few authors referenced the monomial formula under Manning's name, including the 1899 "Elementary Hydraulics" by Willcocks, Buckley's 1913 "Irrigation Pocket Book," the 1913 edition of Parker's "Control of Water," and Dougherty's 1916 "Hydraulics."

But it was probably King (1918) that led to the widespread use of the monomial formula among practicing engineers as well as to the acceptance that Manning's coefficient C should be the inverse of Kutter's n. In his "Handbook of Hydraulics," King evaluated existing formulae and suggested that

> *the same n used in Kutter's and Manning's formulas [this followed a discussion relating Manning's "K" to Kutter's n] gives practically identical results within the limits of our experimental knowledge and throughout the range of ordinary application. This will be shown to be the case and the author believes that the general adoption of the Manning formula, as a substitute for the Kutter formula, will be a step in advance.*

King also included in his handbook a tabulation of the two-thirds power of numbers over the range of 0.01 to 10. This may well have secured acceptance of the formula by overcoming the greatest difficulty in its application.

MODERN ADVANCEMENTS

Prandtl, Blasius, Nikuradse Hopf, von Karman, Colebrook and White, Moody, Keulegan, and others have provided valuable insight into the relations between flow resistance and fluid mechanics subsequent to the formulation of these early resistance relations. Their studies have led to the development of relationships between resistance coefficients and logarithmic and power velocity distributions for flow in channels with rigid boundaries.

The application of both the Manning equation and its modern equivalents presumes that a measure of resistance (e.g. the value of n) is known or can be accurately estimated. Considerable research effort in the mid-20th century was focused on developing good resistance predictors and, by relating the Manning equation to modern logarithmic formulae, resistance coefficients to bed material size or type of bed form. Thus, for fixed beds and alluvial channels in which resistance is due primarily to grain resistance, reasonable estimates can be made using any number of techniques. Guidance for estimating resistance coefficients when vegetation, boulders, or other large resistance elements are present is much more elusive. These subjects are addressed in companion technical notes.

CLOSING COMMENTS

Even the casual observer will be struck by the number of resistance formulae that have been developed for open channel flow since Manning first proposed his monomial formula in a speech to the Institution of Civil Engineers of Ireland on December 4, 1889. Despite the fact that these "new" formulae include many improvements from the standpoint of incorporating fluid mechanics concepts or, if empirically based, are supported by more observations, Manning's monomial formula persists as the most frequently used by hydraulic engineers.

Ironically, Manning's equation (in the form of Equation 4) may have hindered the advancement and acceptance of fluid mechanics concepts by modern hydraulic engineers. Despite the obvious progress in our understanding fluid flow as a result of Prandtl's boundary layer theory and the more recent work on turbulence, no equation for open channel flow has been

advanced that has displaced the Manning equation for practicing hydraulic engineers. This seems remarkable for a rather simple equation that was rejected by its author who was an accountant-turned-self-taught-engineer as a result of the Irish famine.

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